A hybrid TIM-NOMA scheme for the SISO Broadcast Channel

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Abstract—**Future mobile communication networks will require enhanced network efficiency and reduced system overhead due to their user density and high data rate demanding applications of the mobile devices. Research on Blind Interference Alignment (BIA) and Topological Interference Management (TIM) has shown that optimal Degrees of Freedom (DoF) can be achieved, in the absence of Channel State Information (CSI) at the transmitters, reducing the network's overhead. Moreover, the recently emerged Non-Orthogonal Multiple Access (NOMA) scheme suggests a different multiple access approach, compared to the current orthogonal methods employed in 4G networks, resulting in high capacity gains. Our contribution is a hybrid TIM-NOMA scheme in Single-Input-Single-Output (SISO) K-user cells, in which users are divided into T groups, and $1/T$ DoF is achieved for each user. By superimposing users in the power domain, we introduce a two-stage decoding process, managing "inter-group" interference based on the TIM principles, and "intra-group" interference based on Successful Interference Cancellation (SIC), as proposed by NOMA. We show that for high SNR values the hybrid scheme can improve the sum rate by at least 100% when compared to Time Division Multiple Access (TDMA).**

I. INTRODUCTION

Future increase in the number of mobile devices, using data-hungry applications, will lead to highly dense cellular networks, demanding high capacity performance with the least possible system overhead. Interference Alignment (IA), introduced by Maddah-Ali, Motahari and Khandani in [1] and Cadambe and Jafar in [2], allows in the K-user interference channel $K/2$ Degrees of Freedom (DoF) to be achieved, assuming global perfect CSI. IA differs from other interference management schemes, as it attempts to align interference, rather than avoid, reduce or cancel it.

However, IA requirement of full CSI is infeasible and costly. The scheme of Blind IA (BIA), presented by Wang, Gou and Jafar in [3] and Jafar in [4], for certain network scenarios, can achieve full DoF in the absence of CSI at the transmitters (CSIT), reducing considerably the system overhead. Additionally, in [5] Jafar introduces how the BIA scheme can be employed in certain cellular networks, including heterogeneous networks, by seeing frequency reuse as a simple form of IA. In [6], Jafar introduces the Topological Interference Management (TIM) scheme, which can be considered as a form of BIA in

which the position of every user in the cell(s), and therefore the strength of their channels, is taken into account. Requiring only knowledge of the network's topology at the transmitters, 1/2 DoF can be achieved for every user in the SISO Broadcast Channel (BC), by treating weak interference links as noise. Moreover, in [7] Sun and Jafar discuss the implications of increasing the number of receive antennas resulting in an increase on the network's DoF.

In [8], Saito et al. propose a Non-Orthogonal Multiple Access (NOMA) scheme for future radio access, in contrast to the Ortogonal Frequency Division Multiple Access (OFDMA) and Single Carrier-Frequency Division Multiple Access (SC-FDMA) orthogonal schemes currently adopted by 4G mobile systems. According to the NOMA scheme, multiple users are superimposed in the power domain and Successful Interference Cancellation (SIC) reception is performed at the decoding stage, ultimately improving the capacity and throughput performance. Furthermore, Benjebbour et al. in [9] present the benefits of NOMA and discuss its performance considering adaptive modulation and coding, and frequency-domain scheduling. Moreover, Ding and co-authors in [10]-[11] discuss the superior performance of NOMA in terms of ergodic sum rates and the importance of power allocation, and a cooperative NOMA scheme where users with higher channel gains have prior information about other users' messages, respectively. Finally, Ding, Fan and Poor in [12] study user pairing on two NOMA schemes and how it affects the sum rate. The first scheme, F-NOMA, with fixed power allocation, pairs users with very distinctive channel conditions, whereas the second one, CR-NOMA, inspired by cognitive radio, pairs users with similar channel conditions.

In this paper, based on [6] and [8], we introduce a hybrid TIM-NOMA scheme in general K-user SISO cells. Our contribution is the combination of the TIM and NOMA schemes, in a two-stage decoding way, dividing users in T groups. In the first-stage, we apply the TIM scheme to manage "inter-group" interference, with no need to ignore weak interference links. In the second-stage, we employ NOMA, at every group of users separately, to manage "intra-group" interference through SIC. Finally, we discuss how the sum rate performance of the system is significantly improved with the employment of

the hybrid scheme when compared to Time Division Multiple Access (TDMA).

The rest of the paper is organized as follows. Section II presents the general description of the hybrid scheme, with the aid of an example model with $K = 5$ users, including the determination of the transmit power, and the two-stage decoding process. Section III presents the achievable rate formula for every user in the network. Finally, Section IV gives an overview of our results, illustrated with graphs, discussing how the users' distance from the basestation, and the amount of interference they end up considering as noise affects their performance.

II. SYSTEM MODEL

Consider the Broadcast Channel (BC) network, as shown in Figure 1, for $K = 5$ users. At the SISO BC of the cell, there is one transmitter T_x with 1 antenna, and K users equipped with 1 antenna each. Transmitter T_x has 1 message to send to every user, and moreover, when it transmits to user k, where $k \in \{1, 2, ..., K\}$, it causes interference to all the other $K-1$ users in the macrocell. The radius of the cell is considered as $R = 5 \ km$, and the distance of every user from the basestation is given by d_k.

Furthermore, users are divided into T groups $\{G_1, G_2, ..., G_T\}$ in such a way so that there are always $T-1$ users from the remaining $T-1$ groups separating 2 users from the same group, and to place users with considerable difference in their channel strengths in the same group. The operation is performed over T time slots, over which we assume that channel coefficients remain the same. The transmitter has only knowledge of the topology of the network.

According to the NOMA scheme, described fully in [8]-[9], users are multiplexed, in the power domain, at the transmitters, and then at the receivers, signal separation is performed based on SIC. Decoding is performed based on an optimal order (in the order of descreasing channel gains divided by the power of noise and interference), resulting in every user being able to decode the signals of users coming before them in the decoding order.

The general concept of the hybrid TIM-NOMA scheme, is that every user, in order to recover its desired signal, uses the principles of TIM to manage interference coming from transmissions to users NOT belonging to their own group (i.e. their channel strengths are quite similar), and the principles of NOMA to manage interference due to transmissions to users belonging in their own group (i.e. their channel strengths are quite different).

According to our research, NOMA seems to work better when applied to users with considerable difference in their channel gains. Therefore, introducing TIM in the NOMA scheme, and splitting users into groups, provides a solution for the cases where users' gains do not differ much. The aforementioned reason, combined with fact that both schemes do not require CSIT, as discussed in [6] and [9], results in a very smooth and successful combination of them.
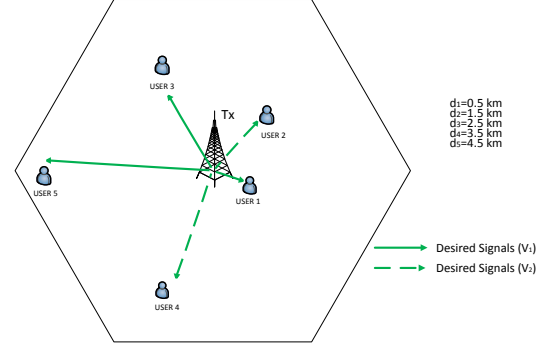

Figure 1. The hybrid NOMA-TIM scheme for a $K = 5$ users cell. Users are divided into $T = 2$ groups: group G_1 (aligned along $\mathbf{V}_1$) with users $1, 3, 5$ and group G_2 (aligned along $\mathbf{V}_2$) with users $2, 4$.

In this paper, we will use an example model, to present the hybrid TIM-NOMA scheme, where we consider $K = 5$ users, $T = 2$ time slots and groups $\{G_1, G_2\}$. Users 1,3 and 5 are in group G_1, and users 2 and 4 are in group G_2. Finally, the users' distances from the transmitter are given by: $d_1 = 0.5$ km, $d_2 = 1.5 \ km$, $d_3 = 2.5 \ km$, $d_4 = 3.5 \ km$, $d_5 = 4.5 \ km$.

A. Transmitted Power

The $T \times 1$ signal at receiver k is given by:

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x} + \mathbf{z}_k \tag{1}$$

Due to the users' different locations, channel coefficients are statistically independent, and follow an i.i.d. Gaussian distribution $\mathcal{CN}(0, 1)$. $\mathbf{H}_k \in \mathbb{C}^{T \times T}$ is the channel transfer matrix from T_x to receiver k and is given by $\mathbf{H}_k = \sqrt{\gamma_k} \left(\mathbf{I}_T \otimes h_k\right)$, (here and throughout $\otimes$ denotes the Kronecker (Tensor) product), with h_k denoting the channel coefficient from T_x to k for one time slot. Moreover, $\gamma_k = \frac{1}{d_k^n}$ denotes the path loss, and n is the path loss exponent considered for an urban environment, i.e. $n = 3$. Finally, $\mathbf{z}_k \sim \mathcal{CN}(0, \sigma_n^2 \mathbf{I}_T)$ denotes independent Additive White Gaussian Noise (AWGN) at the input of receiver k.

Taking into consideration the position of each user k in the cell, and therefore its distance d_k from the basestation, ordering users increasingly, in terms of d_k, the following relationship, regarding their channel gains normalized by the noise power (assuming the same noise power for all receivers), follows:

$$\frac{|h_1|^2}{\sigma_n^2} > \frac{|h_2|^2}{\sigma_n^2} > ... > \frac{|h_{K-1}|^2}{\sigma_n^2} > \frac{|h_K|^2}{\sigma_n^2}, \tag{2}$$

with user 1 being very close to the basestation and user K at the edge of the cell. Therefore, weaker channels, of users' being far from the basestation, need to be boosted, such that the following holds for their transmit power:

$$P_K > P_{K-1} > ... > P_2 > P_1 \tag{3}$$

The energy of the input symbol $x_k \in \mathbb{C}$, of each user k, is defined as:

$$\mathrm{E}\left[|x_k|^2\right] = 1 \qquad (4)$$

For every user k in the cell, we choose to take its transmitted power given by:

$$P_k = a^2 \frac{d_k^2}{\sum_{j=1}^{K} d_j^2}, \qquad (5)$$

where $a \in \mathbb{R}$ is a constant determined by power considerations. The total transmit power is given by the power constraint:

$$P_T = \left(\sum_{j=1}^{K} P_j\right) \mathrm{norm}(x_k) = a^2 \qquad (6)$$

B. Stage 1 - "Inter-group" interference management - Topological Interference Management (TIM) scheme

In the network, there will be T precoding vectors $\mathbf{v}_t$, where $t \in \{1, 2, ..., T\}$, which are $T \times 1$ unit vectors. The choice of precoding vectors, carrying messages to users in the cell, is not unique, and we choose them in such a way so that every precoding vector $\mathbf{v}_t$ is orthogonal to all the remaining $T-1$ precoding vectors.

The $T \times 1$ transmitted vector $\mathbf{x}$ is given by:

$$\mathbf{x} = \sum_{k=1}^{K} \sqrt{P_k} \mathbf{v}_{t(k)} x_k, \qquad (7)$$

with $t(k) \in \{1, 2, ..., T\}$ denoting the number of the group G_t each user k belongs to.

Example 1. For the example model, the precoding vectors $\mathbf{v}_1$ and $\mathbf{v}_2$, for groups G_1 and G_2 respectively, are given by:

$$\mathbf{v}_1 = \begin{bmatrix} 1/2 \\ \sqrt{3}/2 \end{bmatrix} \qquad (8)$$

$$\mathbf{v}_2 = \begin{bmatrix} -\sqrt{3}/2 \\ 1/2 \end{bmatrix}, \qquad (9)$$

and the 2×1 transmitted vector is:

$$\mathbf{x} = \sum_{k=1}^{5} \sqrt{P_k} \mathbf{v}_{t(k)} x_k, \qquad (10)$$

where for $G_1 = \{1, 3, 5\}$ and $G_2 = \{2, 4\}$.

As a result of the way precoding vectos are determined, receivers of the same group G_i see their desired signals along $\mathbf{v}_i$, and undesired signals from users not in their group along remaining $T-1$ precoding vectors $\{\mathbf{v}_j\}$, for $j = 1, ..., T$ and $j \neq i$. Managing interference coming from transmissions from users not belonging in their own group, and based on the example given in [6, Section 4], every receiver k, of the same group G_i, can partially recover their signal by projecting their received signal $\mathbf{y}_k$ along $\mathbf{v}_i$, which by definition is orthogonal to all the other $T-1$ precoding vectors $\{\mathbf{v}_j\}$, for $j = 1, ..., T$ and $j \neq i$.

Theorem 1: *Multiplying the received signal* $\mathbf{y}_k$ *with the transpose of the precoding vector* $\mathbf{v}_i$, *the resulting signal at every receiver* k, *is given by:*

$$\widetilde{\mathbf{y}_k} = \mathbf{v}_i^T \mathbf{H}_k \left(\sum_{j \in G_i} \sqrt{P_j} \mathbf{v}_i x_j\right) + \widetilde{\mathbf{z}_k}$$

$$= \sqrt{\gamma_k} h_k \left(\sum_{j \in G_i} \sqrt{P_j} x_j\right) + \widetilde{\mathbf{z}_k}, \qquad (11)$$

where $k \in G_i$, *and* $\widetilde{\mathbf{z}_k} = \mathbf{v}_i^T \mathbf{z}_k$ *remains white noise with the same variance.*

Proof: We show that $\mathbf{v}_i^T$ removes "inter-group" interference, i.e. interference resulting from transmissions to users in groups $\{G_j\}$ for $j = 1, ..., T$ and $j \neq i$, at the kth receiver:

$$\mathbf{v}_i^T \mathbf{y}_k = \mathbf{v}_i^T \left(\sqrt{\gamma_k}\left(\mathbf{I}_T \otimes h_k\right) \sum_{k=1}^{K} \sqrt{P_k} \mathbf{v}_{t(k)} x_k + \mathbf{z}_k\right)$$

$$= \mathbf{v}_i^T \sqrt{\gamma_k}\left(\mathbf{I}_T \otimes h_k\right) \left(\sum_{j \in G_i} \sqrt{P_j} \mathbf{v}_i x_j\right) + \mathbf{W}_i^T \mathbf{z}_k \qquad (12)$$

where by definition, for $j = 1, ..., T$ and $j \neq i$, $\mathbf{v}_i^T \mathbf{v}_j = 0$. ∎

Example 2. For the example model, for groups G_1 and G_2 respectively:

$$\mathbf{v}_1^T = \begin{bmatrix} \frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \qquad (13)$$

$$\mathbf{v}_2^T = \begin{bmatrix} \frac{-\sqrt{3}}{2} & \frac{1}{2} \end{bmatrix} \qquad (14)$$

The 1×1 post-processed signals at receivers are: for $i = 1, 3, 5$:

$$\widetilde{\mathbf{y}}_i = \mathbf{v}_1^T \mathbf{H}_i \left(\sum_{j=1,3,5} \sqrt{P_j} \mathbf{v}_1 x_j\right) + \mathbf{v}_1^T \mathbf{z}_1 \qquad (15)$$

and for $i = 2, 4$:

$$\widetilde{\mathbf{y}}_i = \mathbf{v}_2^T \mathbf{H}_i \left(\sum_{j=2,4} \sqrt{P_j} \mathbf{v}_2 x_j\right) + \mathbf{v}_2^T \mathbf{z}_2 \qquad (16)$$

C. Stage 2 - "Intra-group" interference management - Non-Orthogonal Multiple Access (NOMA) scheme

The concept of NOMA will be applied in each group G_t separately. Based on [8, Section 3], for every group G_t, the SIC process is applied at every receiver. All users are ordered increasingly by their channel gain $|h_k|^2$ normalized by the noise power σ_n^2. Each user k can correctly decode the signals of users, in their own group, whose channel gain by noise power ratio is smaller than theirs, i.e. come before them in (2), by considering their own signal as noise. In the case where user

k receives interference from transmissions to users in their own group that have a higher channel gain by noise power ratio than they do, then user k simply decodes its own signal considering "intra-group" interference from users, in their own group, who come after them in (2), as noise. Maximum-Likelihood (ML) reception is performed every time a user decodes its own or another user's signal.

Example 3. For the example-model, the decoding order for the users is:

$$\frac{|h_1|^2}{\sigma_n^2} > \frac{|h_2|^2}{\sigma_n^2} > \frac{|h_3|^2}{\sigma_n^2} > \frac{|h_4|^2}{\sigma_n^2} > \frac{|h_5|^2}{\sigma_n^2} \tag{17}$$

In group G_1: Receiver 5 decodes its own signal, considering interference from transmissions to users 1 and 3 as noise.

Receiver 3 decodes first signal x_5 (finding $\widetilde{x_5}$), considering its own signal as noise, and substracts the estimate $\widetilde{x_5}$ from its post-processed signal $\widetilde{\mathbf{y}}_3$. Then, it decodes its own signal, considering interference from transmissions to user 1 as noise:

$$\widetilde{\widetilde{\mathbf{y}_3}} = \left(\widetilde{\mathbf{y}_3} - \mathbf{v}_1^T \sqrt{\gamma_3}\left(\mathbf{I}_T \otimes h_3\right)\mathbf{v}_1\widetilde{x_5}\right) \tag{18}$$

Receiver 1 decodes first signal x_5 (finding $\widetilde{x_5}$) and then x_3 (finding $\widetilde{x_3}$) , substracting every time the estimate of the interfering signal from its post-processed one, considering its own signal as noise, eventually decoding its own, interference-free, signal:

$$\widetilde{\widetilde{\mathbf{y}_1}} = \left(\widetilde{\mathbf{y}_1} - \mathbf{v}_1^T \sqrt{\gamma_1}\left(\mathbf{I}_T \otimes h_1\right)\mathbf{v}_1\widetilde{x_5}\right) - \mathbf{v}_1^T \sqrt{\gamma_1}\left(\mathbf{I}_T \otimes h_1\right)\mathbf{v}_1\widetilde{x_3} \tag{19}$$

In group G_2: Receiver 4 decodes its own signal, considering interference from transmissions to user 2 as noise.

Finally, receiver 2 decodes first signal x_4 (finding $\widetilde{x_4}$), considering its own signal as noise, and substracts the estimate $\widetilde{x_4}$ from its post-processed signal $\widetilde{\mathbf{y}}_2$. Then, it decodes its own signal:

$$\widetilde{\widetilde{\mathbf{y}_2}} = \left(\widetilde{\mathbf{y}_2} - \mathbf{v}_2^T \sqrt{\gamma_2}\left(\mathbf{I}_T \otimes h_2\right)\mathbf{v}_2\widetilde{x_4}\right) \tag{20}$$

III. ACHIEVABLE RATE

Since there is no CSIT, the total rate for each user k, in group G_t, per time slot, setting $D = \sum_{j=1}^{K} d_j^2$, is given by:

$$R_k = \frac{1}{T}\log\left(1 + \frac{P_T}{\sum_{\substack{j \in G_t \\ j < k}} |\mathbf{H}_k\mathbf{v}_t|^2 P_j + \sigma_n^2} \frac{d_k^2}{D}\left|\mathbf{v}_t^T\mathbf{H}_k\mathbf{v}_t\right|^2\right), \tag{21}$$

where $k \in G_t$.

If only one user k is active, with all other users shut down, the achievable rate, per time slot, is given by:

$$R_k = \frac{1}{T}\log\left(1 + \frac{P_T}{\sigma_n^2}|\mathbf{H}_k\mathbf{v}_t|^2\right) \tag{22}$$

Example 4. For the example model, the achievable rate, setting $D = \sum_{j=1}^{5} d_j^2$, for every user is given by:

$$R_1 = \frac{1}{2}\log\left(1 + \frac{P_T}{\sigma_n^2}\frac{d_1^2}{D}\left|\mathbf{v}_1^T\mathbf{H}_1\mathbf{v}_1\right|^2\right) \tag{23}$$

$$R_2 = \frac{1}{2}\log\left(1 + \frac{P_T}{\sigma_n^2}\frac{d_2^2}{D}\left|\mathbf{v}_2^T\mathbf{H}_2\mathbf{v}_2\right|^2\right) \tag{24}$$

$$R_3 = \frac{1}{2}\log\left(1 + \frac{P_T}{\left(|\mathbf{H}_3\mathbf{v}_1|^2 P_1\right) + \sigma_n^2}\frac{d_3^2}{D}\left|\mathbf{v}_1^T\mathbf{H}_3\mathbf{v}_1\right|^2\right) \tag{25}$$

$$R_4 = \frac{1}{2}\log\left(1 + \frac{P_T}{\left(|\mathbf{H}_4\mathbf{v}_2|^2 P_2\right) + \sigma_n^2}\frac{d_4^2}{D}\left|\mathbf{v}_2^T\mathbf{H}_4\mathbf{v}_2\right|^2\right) \tag{26}$$

$$R_5 = \frac{1}{2}\log\left(1 + \frac{P_T}{\left(|\mathbf{H}_5\mathbf{v}_1|^2 (P_1 + P_3)\right) + \sigma_n^2}\frac{d_5^2}{D}\left|\mathbf{v}_1^T\mathbf{H}_5\mathbf{v}_1\right|\right) \tag{27}$$

IV. OVERVIEW OF RESULTS

Our simulations were based on the example model already described. The statistical model chosen was i.i.d. Rayleigh and our input symbols were QPSK modulated. Maximum-Likelihood (ML) detection was performed in the end of the decoding stage. The total transmit power was considered as 40W (a typical value for transmit power in macrocells for 4G systems), and therefore a, a constant determined by power considerations in (5) and (6), is given by $a = \sqrt{40}$. Moreover, simulations were performed for $100 - 500$ frames, with each frame consisting of 6144 bits.

A. Degrees of Freedom (DoF)

In [6], with the TIM scheme, the DoF that can be achieved for every user are 0.5 DoF, i.e. one message sent over two time slots. In [8], with the NOMA scheme, 1 DoF can be achieved for every user. Introducing the hybrid scheme, results in optimal DoF for the SISO BC channel in the cell, i.e.

$$DoF_{total} = K/T \tag{28}$$

B. Bit Error Rate (BER) Performance

First of all, the BER performance of our example model was investigated. Based on our findings, the distance of every user k from the transmitter is a key feature that determines the BER performance of every user. In Figure 2, it can be observed that users who are closer to the basestation, like users 1 and 2 have a better performance than users who are far from the basestation, like users 4 and 5.

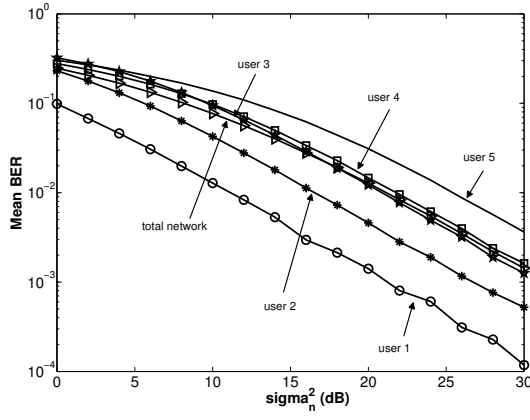Moreover, in Figure 3, a comparison between the BER performance of users shown in Figure 2, and the performance

Figure 2. BER performance of the total network and every user separately. the closer a user is to the basestation, the better its BER performance is.
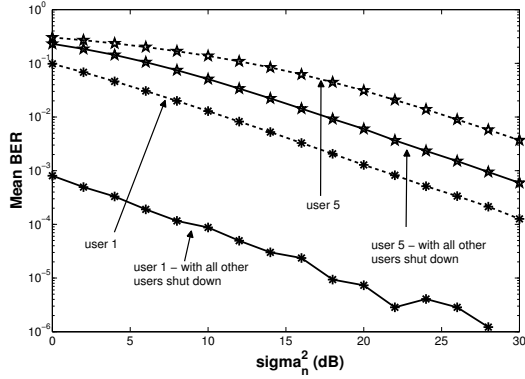

Figure 3. BER performance of every user for the hybrid scheme compared to the one if all other users were shut down. For all users performance is better, when only one user is active. The closer the user is to the basestation the less the improvement is on their BER performance, when shutting down all other users.

they would achieve if all other users were shut down, is shown. For matters of simplicity, only users 1 and 5 are studied, as the performances of the remaining users lie in between. As it can be observed, generally, BER performances are better when only one user is active. Furthermore, the closer a user is to the transmitter, the less improvement we observe in their performance, in the case where all other users are inactive.

C. Rate Performance

The rate of the network will be a function of the user's distance from the basestation and the amount of interference considered as noise, if any, as shown in (21). In Figure 4, it can be observed that the rate decreases with the distance of the user from the transmitter and the amount of interference considered as noise. In particular, user 1, who is the closest to the basestation and manages all interference during the decoding stage, achieves the best rate performance. On the contrary, user 5, who is the furthest from the basestation and considers all "intra-group" interference as noise, achieves the worst performance.
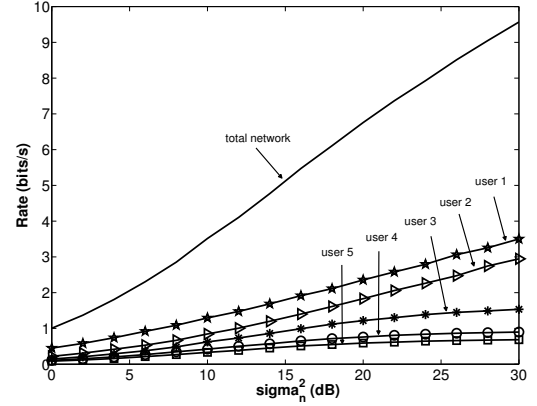

Figure 4. Rate performance of the total network and every user separately. The closer a user is to the basestation, the better its rate performance is.
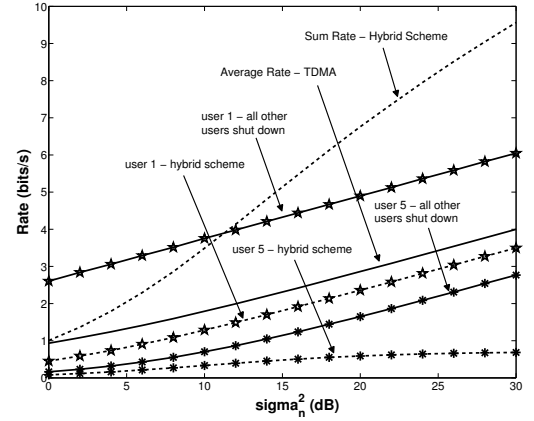

Figure 5. Rate performance of every user for the hybrid scheme compared to the one if all other users were shut down. For all users, their rate would be better if other users were shut down, when compared to their rate in the hybrid scheme. However, the sum rate for the hybrid scheme is better, for high SNRs, than the rate of user 1, when all other users are shut down, implying the gain in terms of sum rate the hybrid scheme provides.
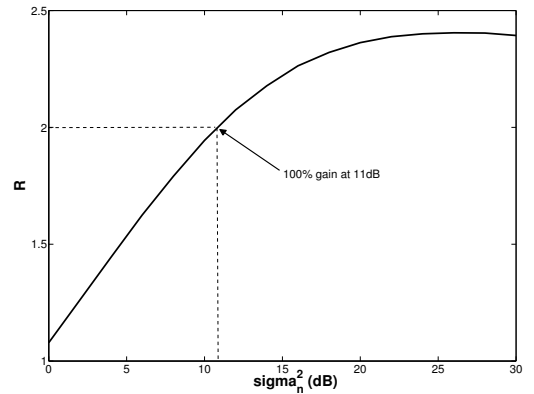

Figure 6. Ratio of sum rate of hybrid scheme over sum rate of TDMA. For SNR values greater than 11dB the gain, of employing the hybrid scheme, is higher than 100%.

Furthermore, Figure 5 depicts a comparison between the rate for every user shown in Figure 4, and the rate they would achieve if all other users were shut down, as given by (22). Again, for matters of simplicity only the cases of users 1 and 5 are shown. As it can observed, rate performances are better when only one user is active. The most important and interesting observation is that the sum rate for the hybrid scheme, for high SNR values, is better than the sum rate of TDMA, proving the gain in terms of rate that the employment of the hybrid scheme results in. Finally, this gain is depicted clearly in Figure 6, where the value of the ratio

$$\mathrm{R} = \frac{\mathrm{R_{HS}}}{\mathrm{R_{TDMA}}}, \qquad (29)$$

where $\mathrm{R_{HS}}$ is the sum rate of the hybrid scheme and $\mathrm{R_{TDMA}}$ is the sum rate for TDMA, is studied for a range of SNR values. For SNR values greater than 11 dB, the performance of the hybrid scheme achieves at least double the rate that would be achieved by TDMA.

V. SUMMARY

Overall, this paper introduces a novel hybrid scheme that can be employed in the SISO BC of a cell, with K users divided into T groups. The hybrid scheme combines basic principles of the TIM and NOMA schemes, by treating "inter-group" interference and "intra-group" interference separately and by a different method. Moreover, the employment of TIM in the cases where users' gains do not differ much, solves performance issues that were faced by NOMA. Furthermore, the system's complexity is reduced, providing flexibility, when compared to the NOMA scheme, without decreasing the rate performance that the system would have if NOMA was only applied. In general, the employment of the proposed scheme results in high data rates, very good BER performance, and reduced system overhead (due to the absence of CSIT requirement). Most interestingly, for high SNRs, the total sum rate is higher than the sum rate for TDMA, proving the gain in terms of sum rate the hybrid scheme results in. The non-complex concept of the hybrid TIM-NOMA scheme introduced in this paper, suggests that it could be employed in dense networks, and potentially in heterogeneous networks once certain adjustments in the algorithm are made.

VI. ACKNOWLEDGEMENTS

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